



Hybrid Heat Pump Solutions for Industrial Energy Savings

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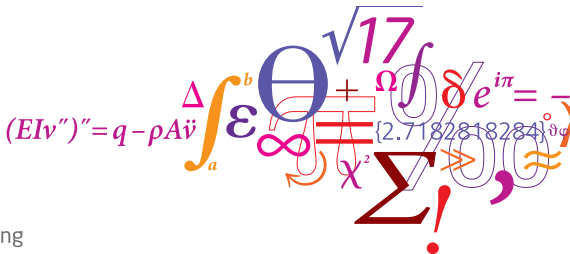
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Hybrid Heat Pump Solutions for Industrial Energy Savings

DTU International Energy Conference
September 10th-12th 2013

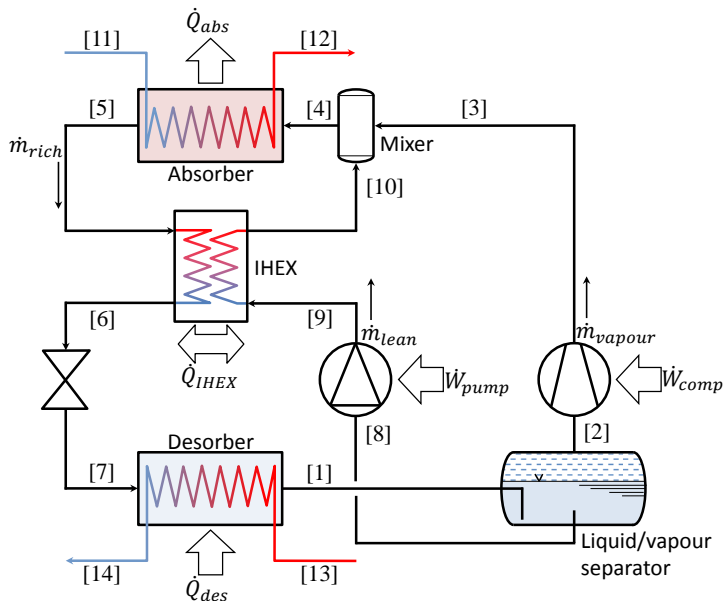
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Department of Mechanical Engineering



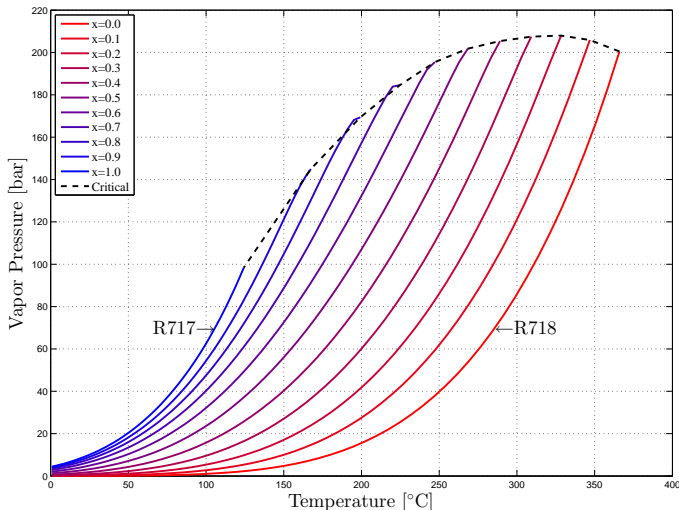
- Introduction to the hybrid absorption compression heat pump
- Advantages of zeotropic mixtures specifically $\text{NH}_3/\text{H}_2\text{O}$
- Evaluation of important design parameters.
- Prospect for high temperature development $T_{supply} < 110^\circ\text{C}$.
- Conclusion & future work

The Hybrid Heat Pump



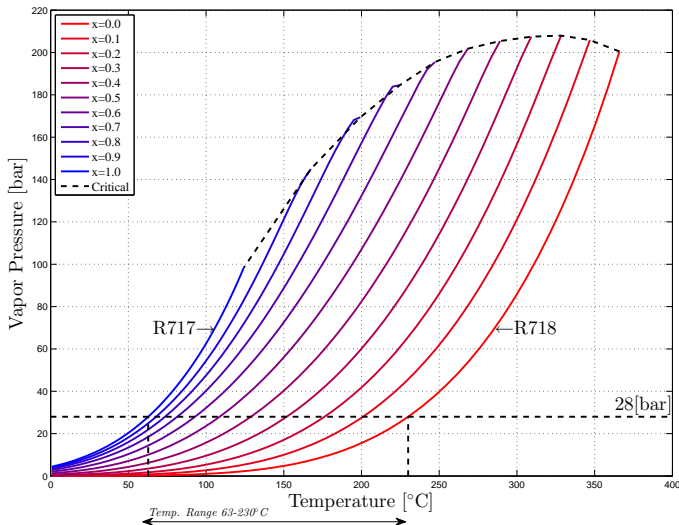
Advantages of Zeotropic Mixtures

Reduction of Vapor Pressure



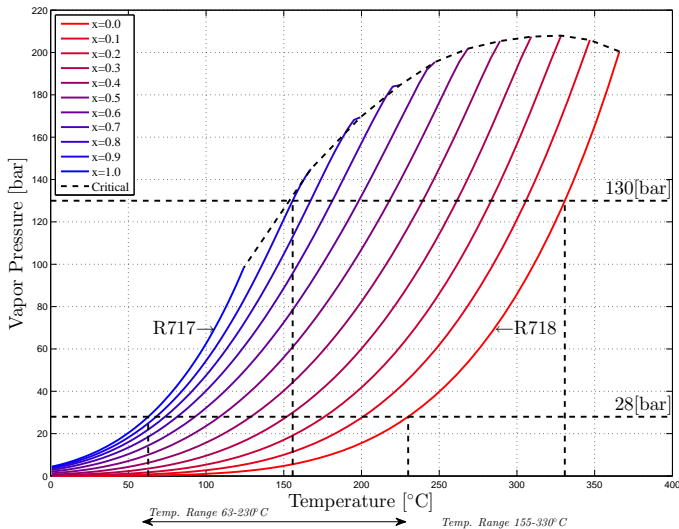
Advantages of Zeotropic Mixtures

Reduction of Vapor Pressure



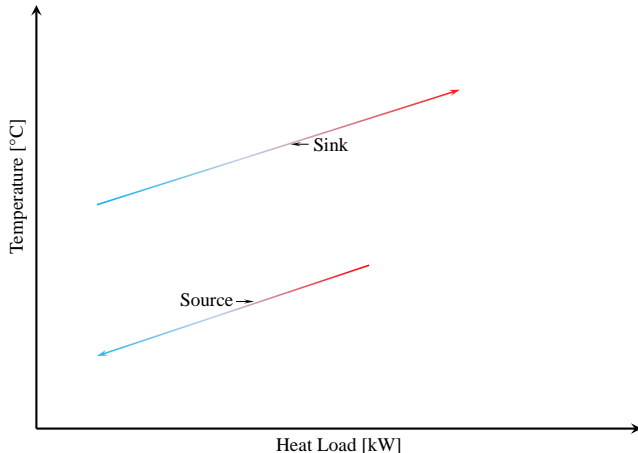
Advantages of Zeotropic Mixtures

Reduction of Vapor Pressure



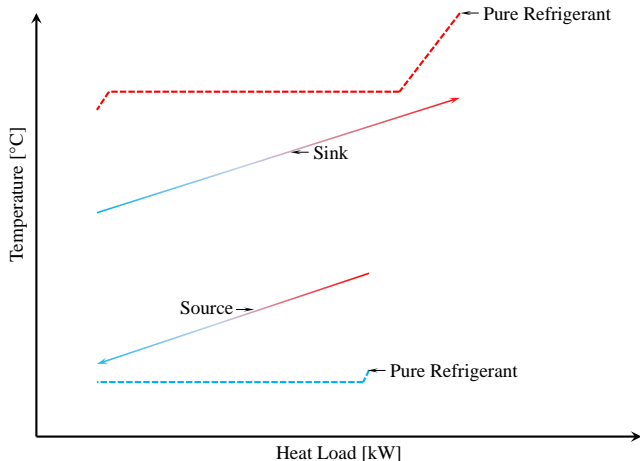
Advantages of Zeotropic Mixtures

Reduction of Entropy Generation



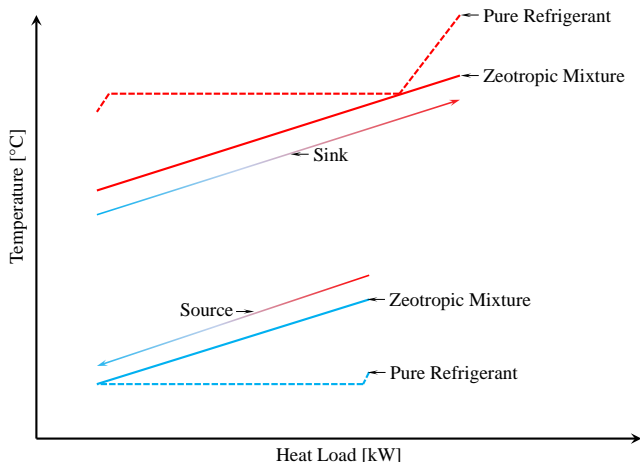
Advantages of Zeotropic Mixtures

Reduction of Entropy Generation



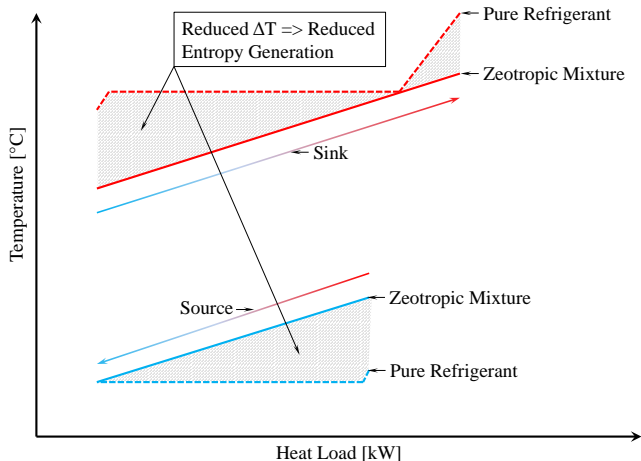
Advantages of Zeotropic Mixtures

Reduction of Entropy Generation



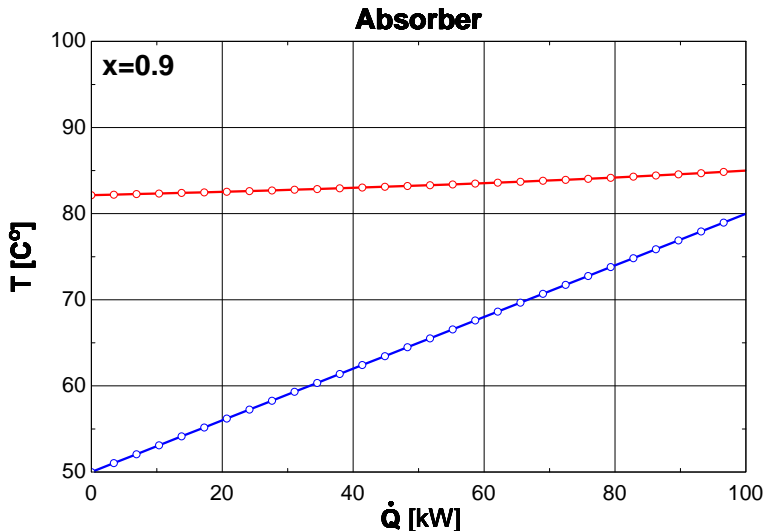
Advantages of Zeotropic Mixtures

Reduction of Entropy Generation



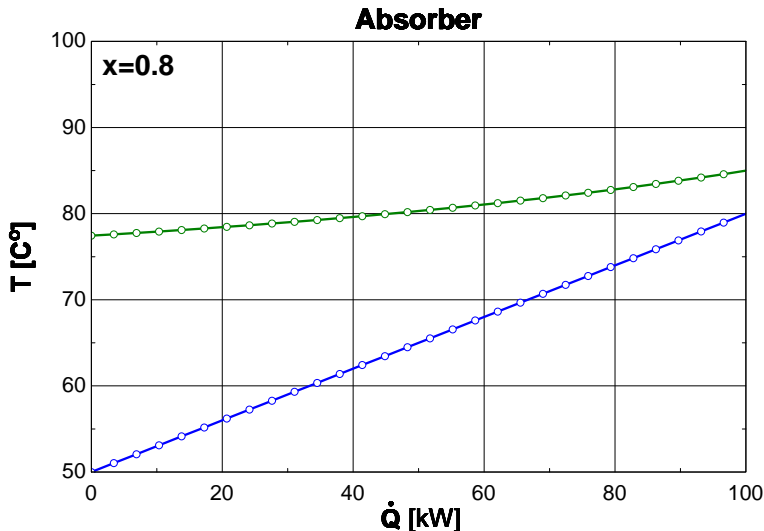
Advantages of Zeotropic Mixtures

Reduction of Entropy Generation



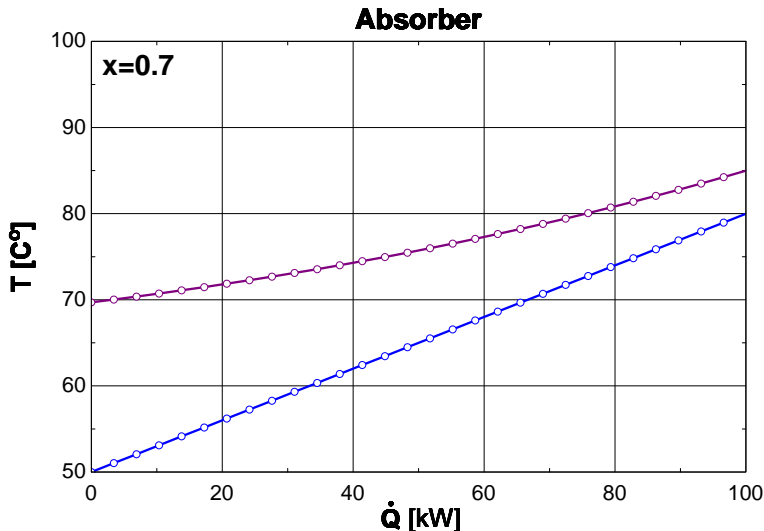
Advantages of Zeotropic Mixtures

Reduction of Entropy Generation



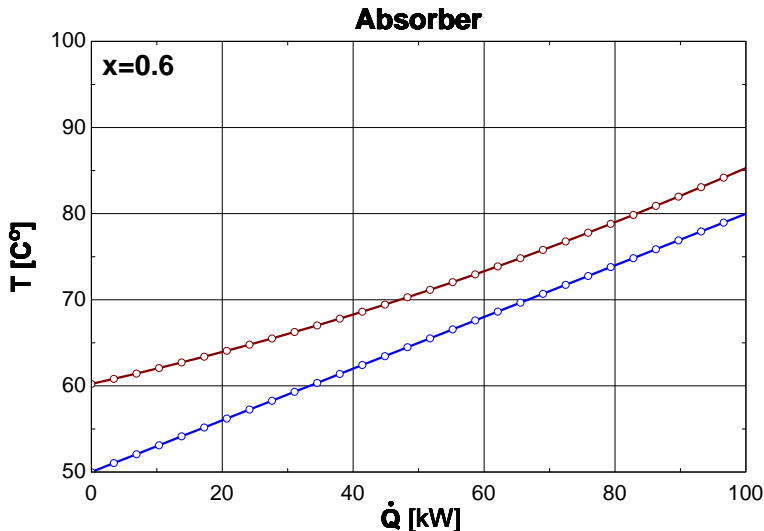
Advantages of Zeotropic Mixtures

Reduction of Entropy Generation



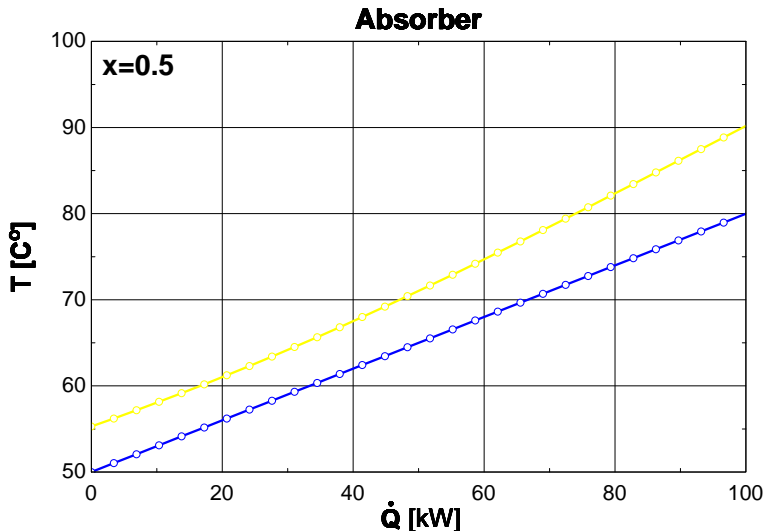
Advantages of Zeotropic Mixtures

Reduction of Entropy Generation



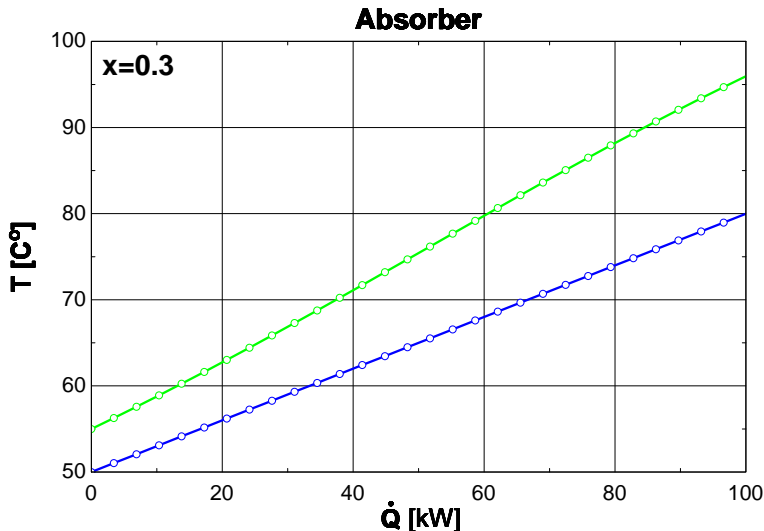
Advantages of Zeotropic Mixtures

Reduction of Entropy Generation



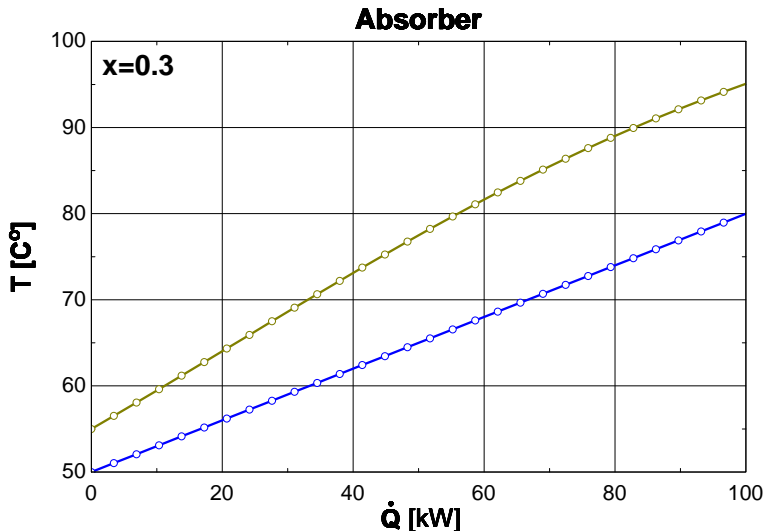
Advantages of Zeotropic Mixtures

Reduction of Entropy Generation



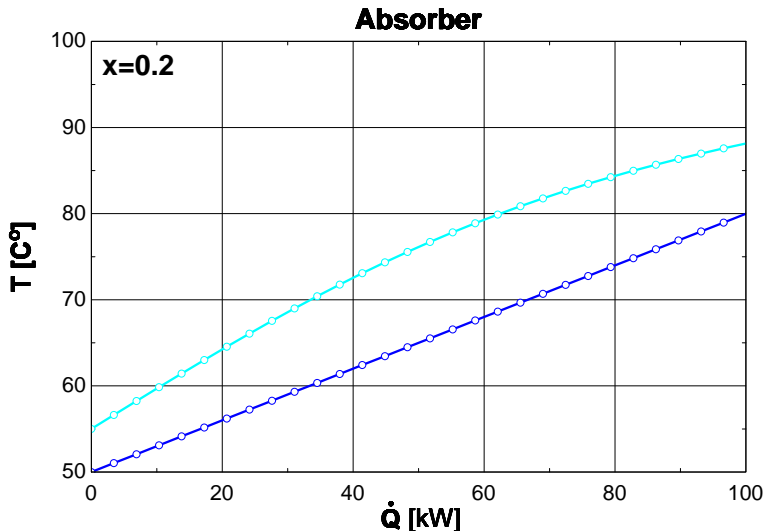
Advantages of Zeotropic Mixtures

Reduction of Entropy Generation



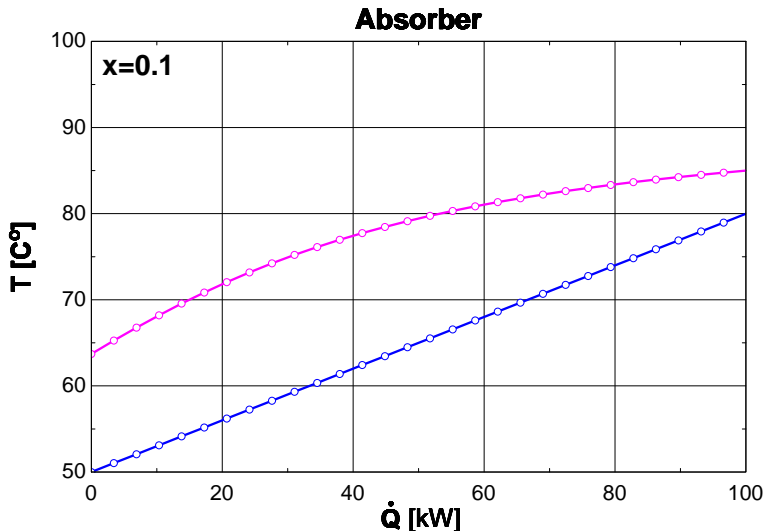
Advantages of Zeotropic Mixtures

Reduction of Entropy Generation

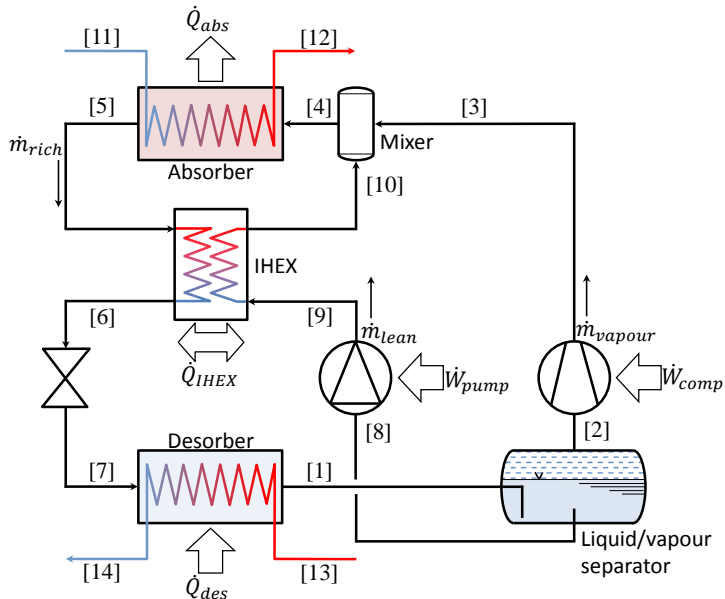


Advantages of Zeotropic Mixtures

Reduction of Entropy Generation



The Hybrid Heat Pump: Design parameters x_r & f



Influence of x_r & f : $T_{sink,out} = 110^\circ\text{C}$, $\Delta T_{lift} = 30^\circ\text{C}$

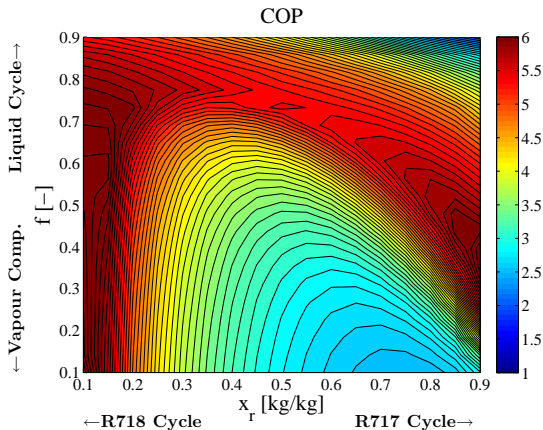
Inputs and Assumptions

External Inputs	
$T_{sink,in}$	$= 80^\circ\text{C}$
$T_{sink,out}$	$= 110^\circ\text{C}$
$T_{source,in}$	$= 80^\circ\text{C}$
\dot{m}_{sink}	$= 1\text{kg/s}$
\dot{m}_{source}	$= 10\text{kg/s}$

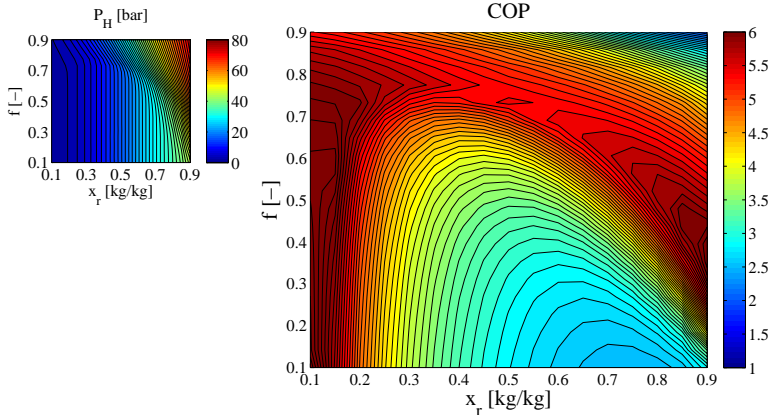
Internal Inputs	
$\Delta T_{pinch,abs}$	$= 5^\circ\text{C}$
$\Delta T_{pinch,des}$	$= 5^\circ\text{C}$
$\eta_{is,comp}$	$= 0.7$
$\eta_{is,pump}$	$= 0.7$
ϵ_{IHEX}	$= 0.8$

Pressure drops are neglected.

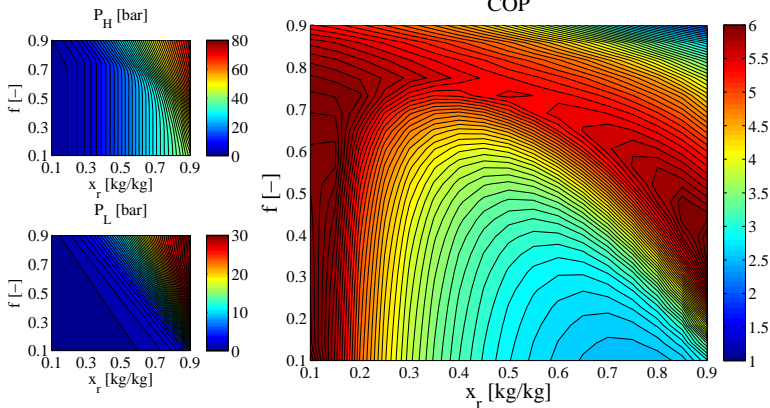
Influence of x_r & f : $T_{sink,out} = 110^\circ C$, $\Delta T_{lift} = 30^\circ C$



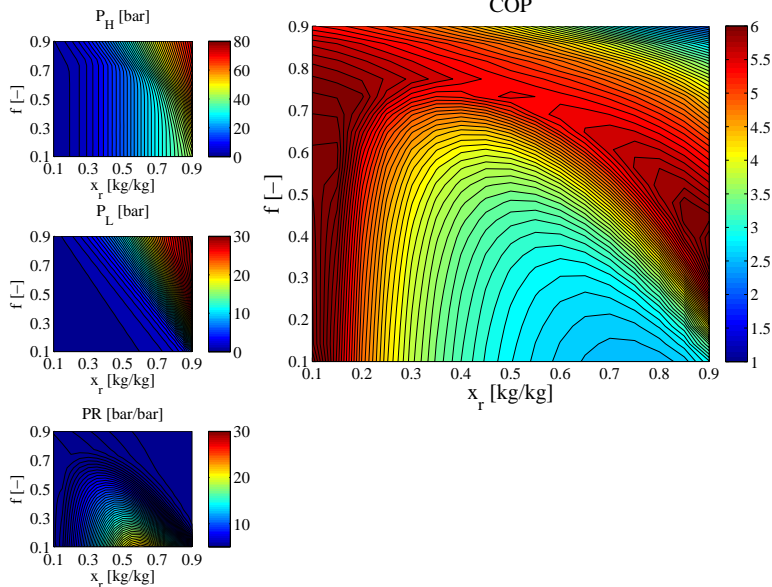
Influence of x_r & f : $T_{sink,out} = 110^\circ C$, $\Delta T_{lift} = 30^\circ C$



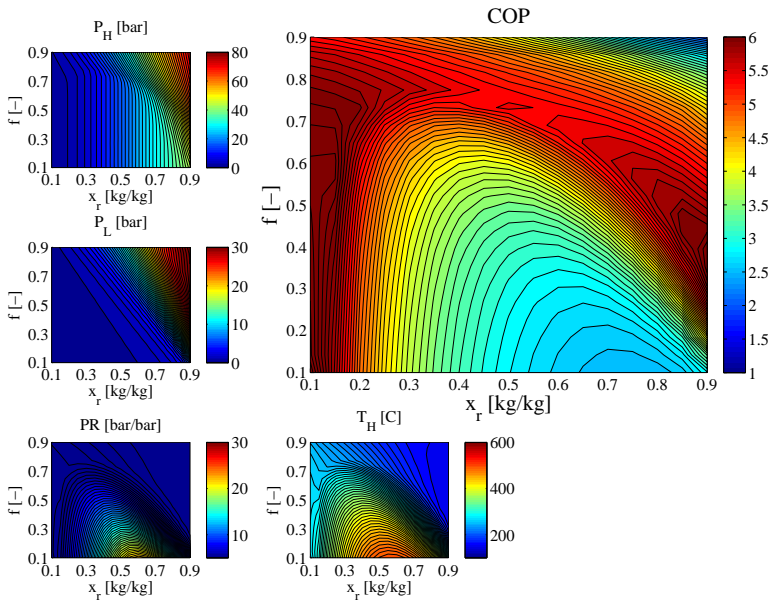
Influence of x_r & f : $T_{sink,out} = 110^\circ C$, $\Delta T_{lift} = 30^\circ C$



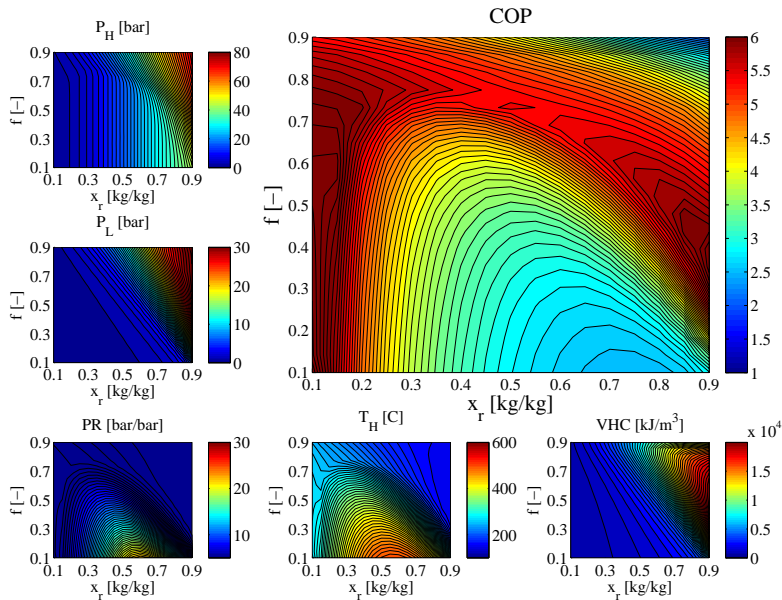
Influence of x_r & f : $T_{sink,out} = 110^\circ C$, $\Delta T_{lift} = 30^\circ C$



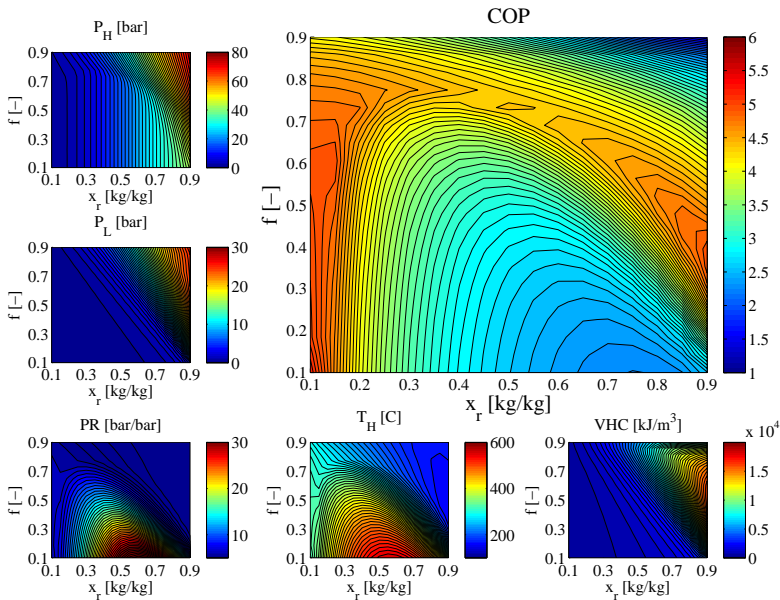
Influence of x_r & f : $T_{sink,out} = 110^\circ C$, $\Delta T_{lift} = 30^\circ C$



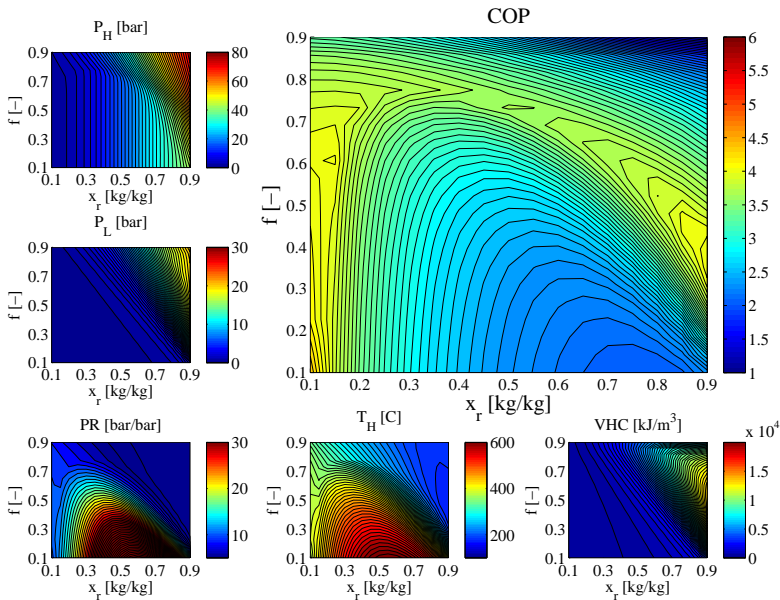
Influence of x_r & f : $T_{sink,out} = 110^\circ C$, $\Delta T_{lift} = 30^\circ C$



Influence of x_r & f : $T_{sink,out} = 110^\circ C$, $\Delta T_{lift} = 40^\circ C$



Influence of x_r & f : $T_{sink,out} = 110^\circ C$, $\Delta T_{lift} = 50^\circ C$

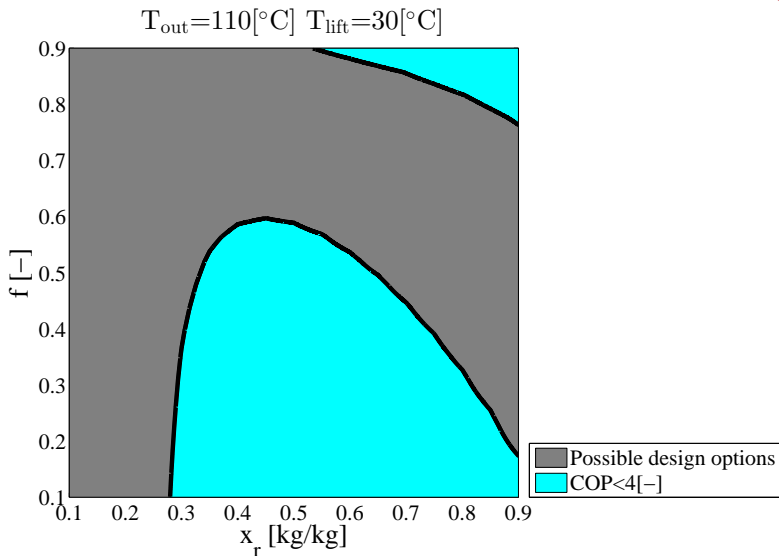


Working domain hybrid heat pumps

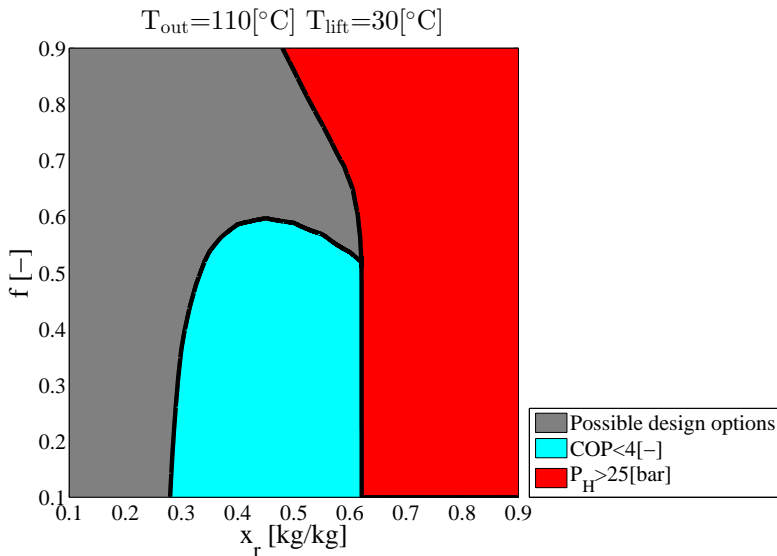
Constraints corresponding to standard refrigeration components

Design Constraints		
COP	$> 4[-]$	Economic
P_H	$< 25[bar]$	Standard refrigeration equipment
P_L	$> 1[bar]$	No entrainment of air from ambient
VHC	$> 2[MJ/m^3]$	Economic ($\dot{Q}_{abs}/\dot{V}_{suc,comp}$)
T_H	$< 160[^\circ C]$	Thermal stability of oil

Working domain hybrid heat pumps

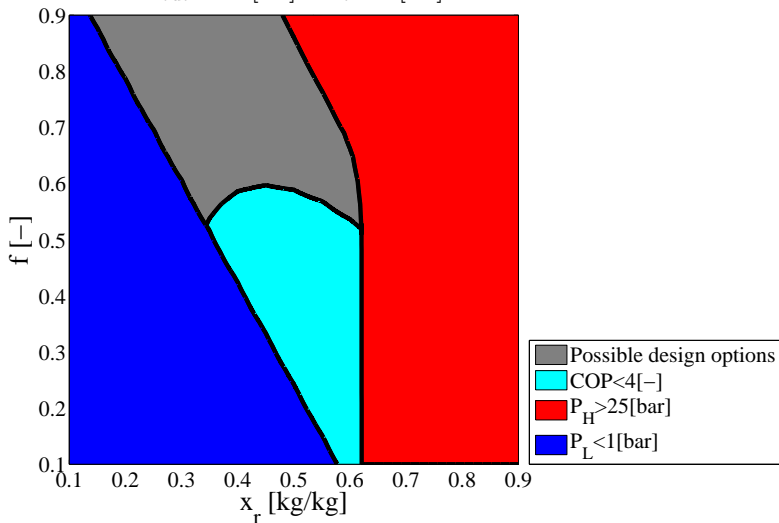


Working domain hybrid heat pumps

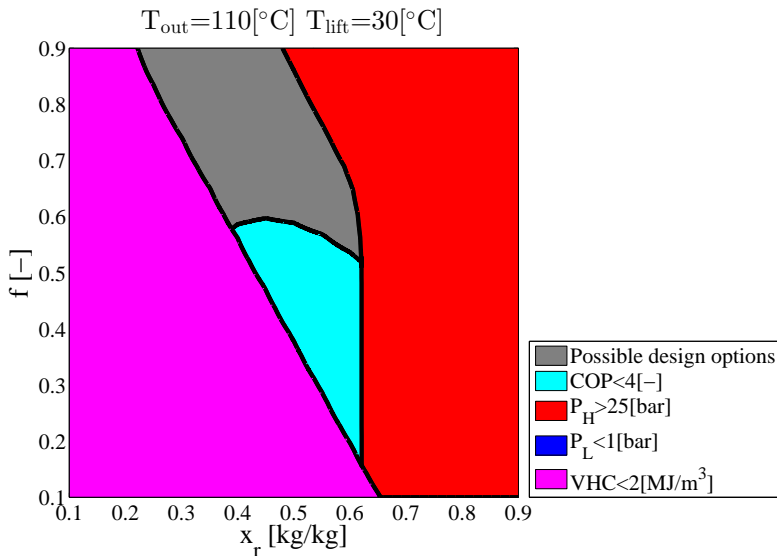


Working domain hybrid heat pumps

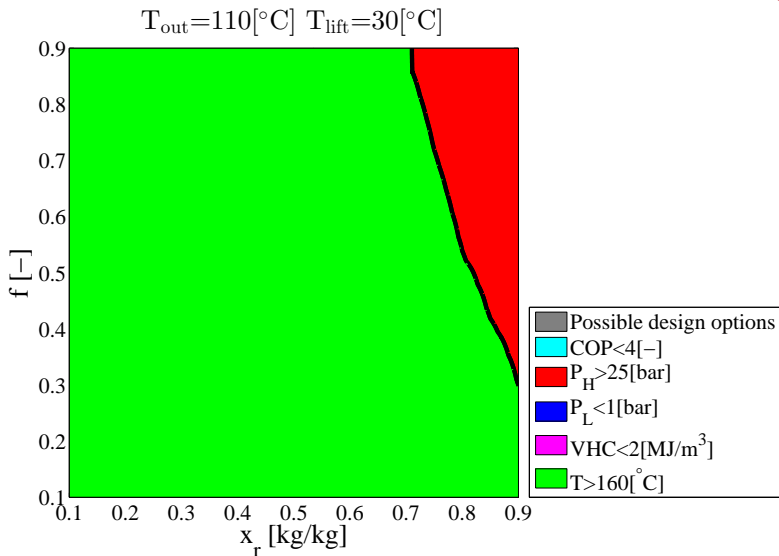
$$T_{\text{out}}=110[^\circ\text{C}] \quad T_{\text{lift}}=30[^\circ\text{C}]$$



Working domain hybrid heat pumps



Working domain hybrid heat pumps

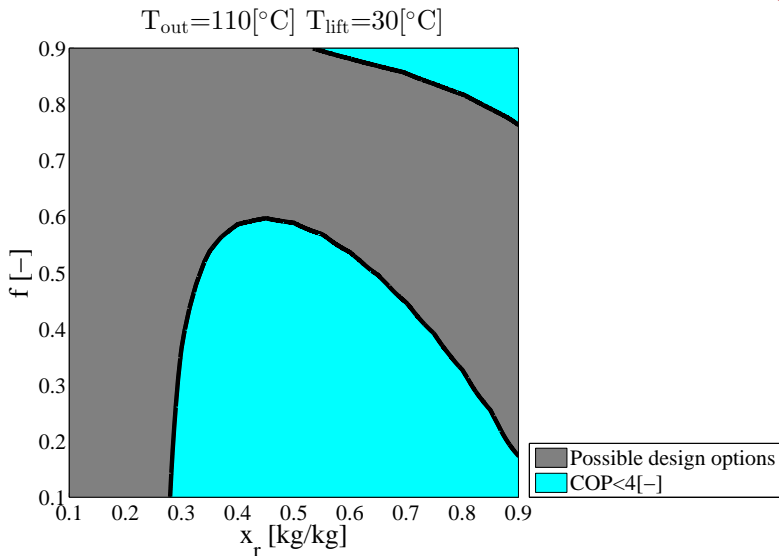


Working domain hybrid heat pumps

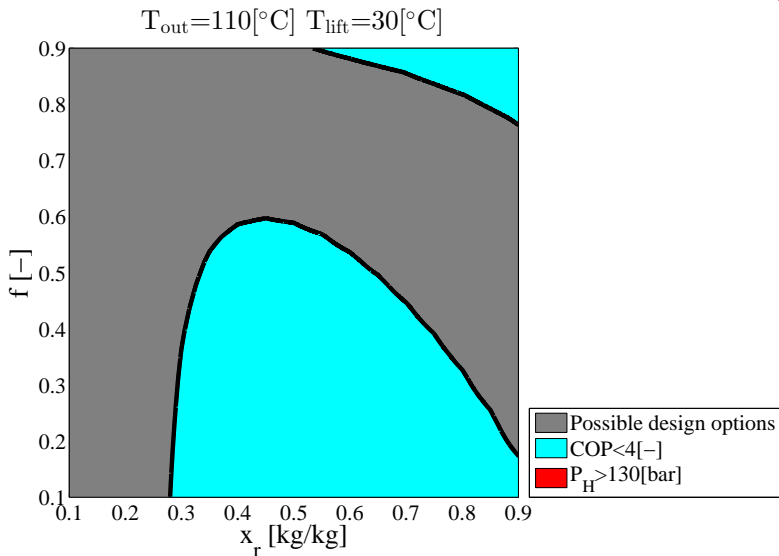
Constraints corresponding to supercritical CO₂ refrigeration components and new synthetic oils

Design Constraints		
COP	$> 4[-]$	Economic
P_H	$< 130[bar]$	Standard refrigeration equipment
P_L	$> 1[bar]$	No entrainment of air from ambient
VHC	$> 4[MJ/m^3]$	Economic ($\dot{Q}_{abs}/\dot{V}_{suc,comp}$)
T_H	$< 250[^\circ C]$	Thermal stability of oil

Working domain hybrid heat pumps

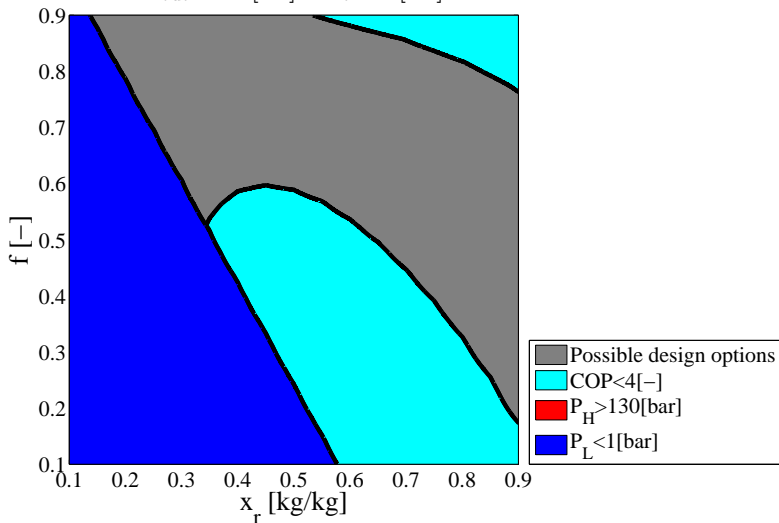


Working domain hybrid heat pumps



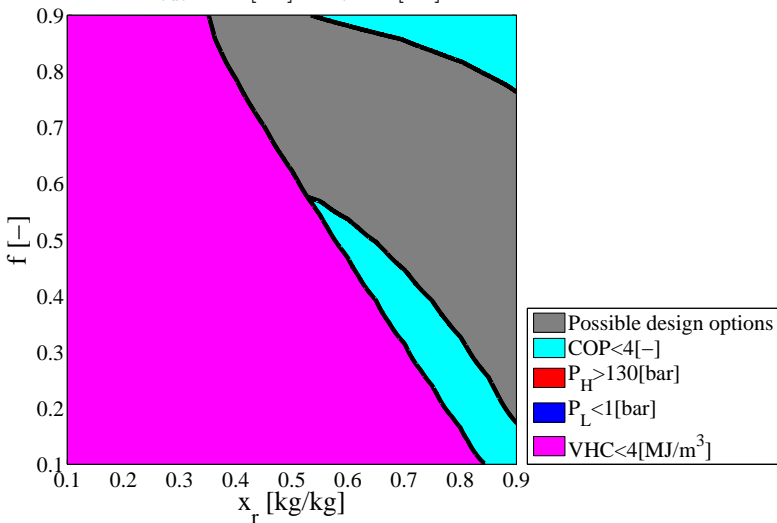
Working domain hybrid heat pumps

$$T_{\text{out}}=110[^\circ\text{C}] \quad T_{\text{lift}}=30[^\circ\text{C}]$$

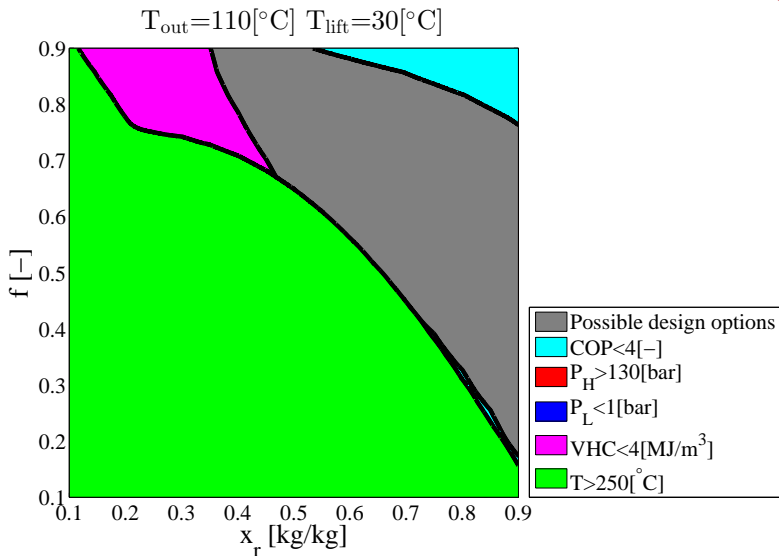


Working domain hybrid heat pumps

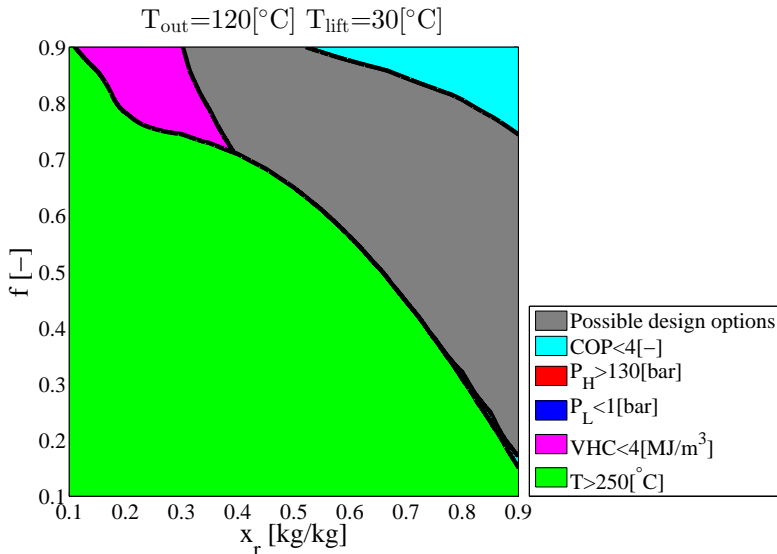
$$T_{\text{out}}=110[^\circ\text{C}] \quad T_{\text{lift}}=30[^\circ\text{C}]$$



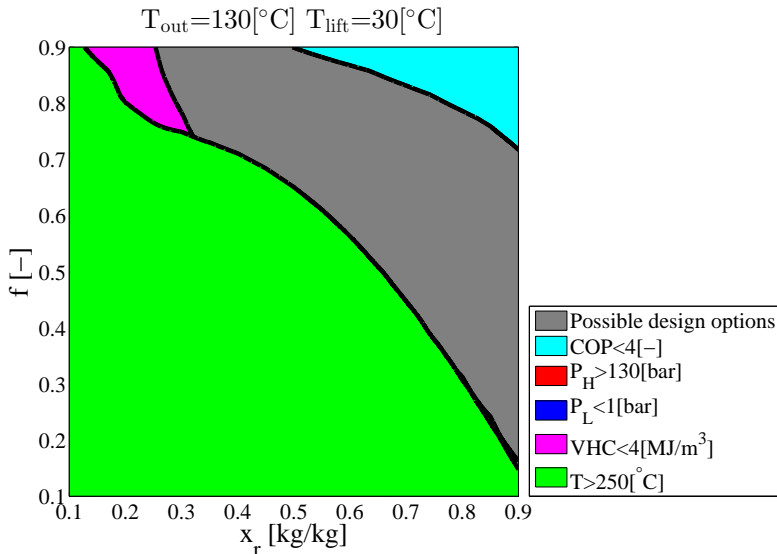
Working domain hybrid heat pumps



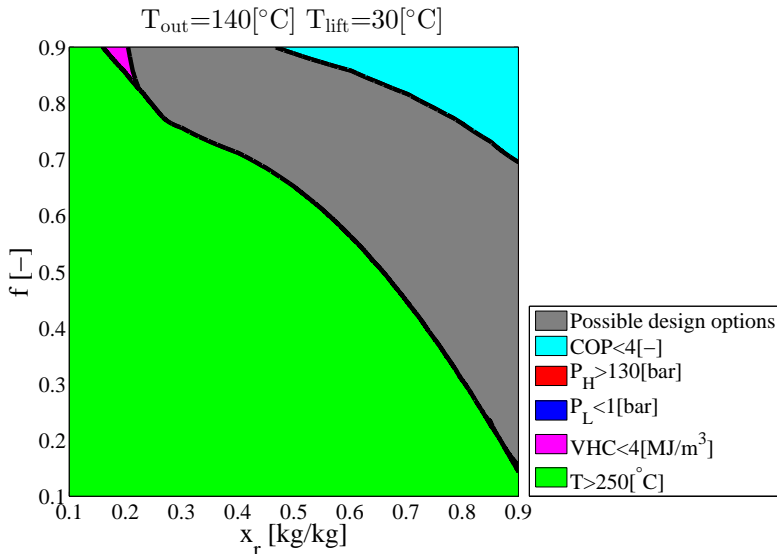
Working domain hybrid heat pumps: $T_{sink,out}$



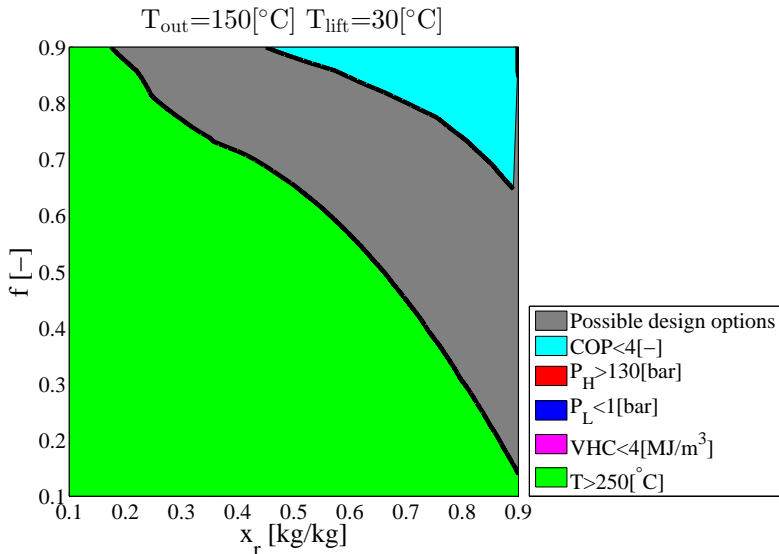
Working domain hybrid heat pumps: $T_{sink,out}$



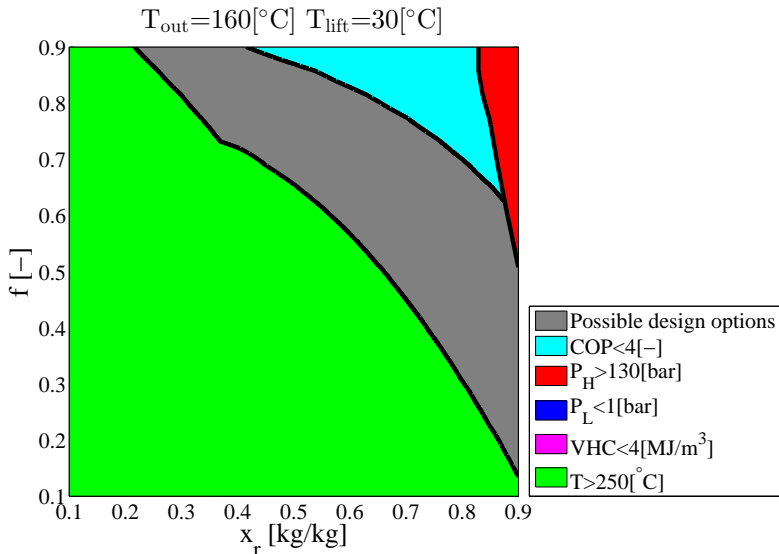
Working domain hybrid heat pumps: $T_{sink,out}$



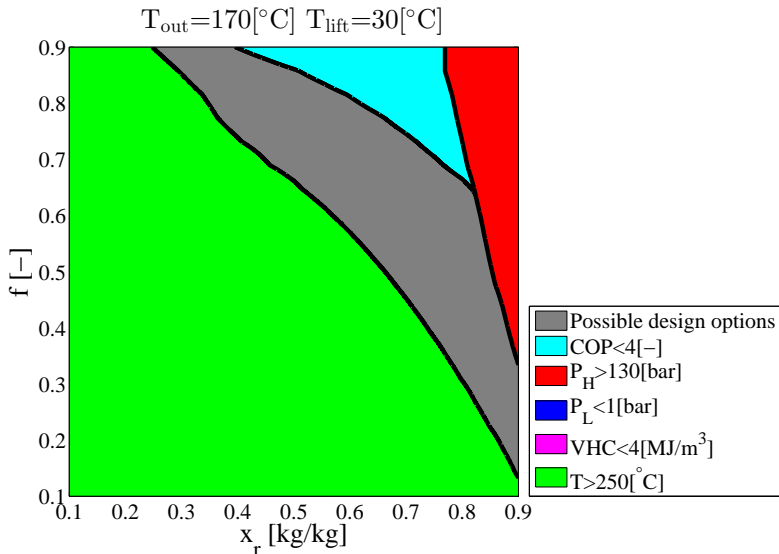
Working domain hybrid heat pumps: $T_{sink,out}$



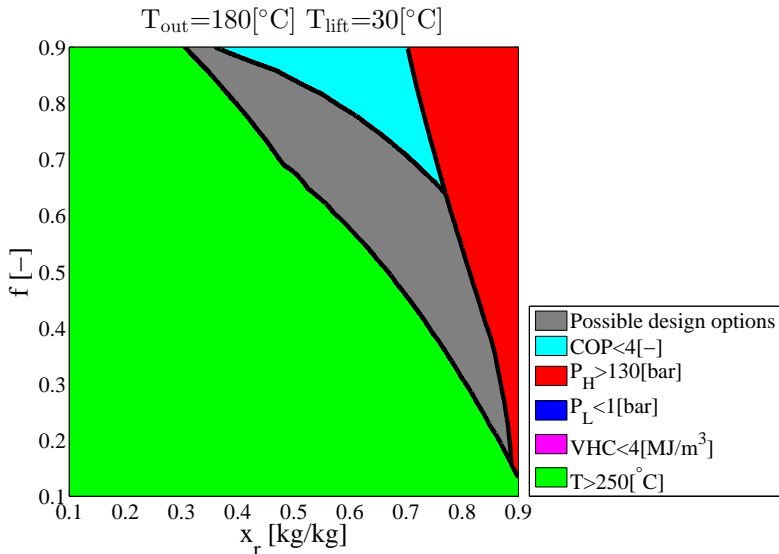
Working domain hybrid heat pumps: $T_{sink,out}$



Working domain hybrid heat pumps: $T_{sink,out}$

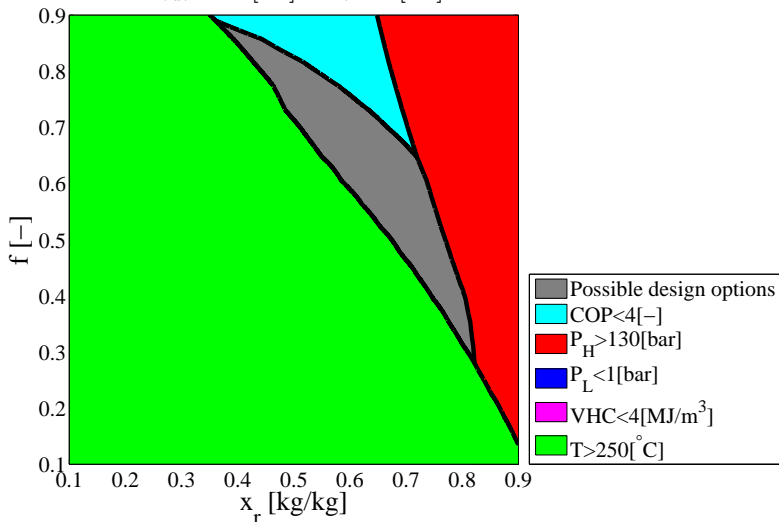


Working domain hybrid heat pumps: $T_{sink,out}$

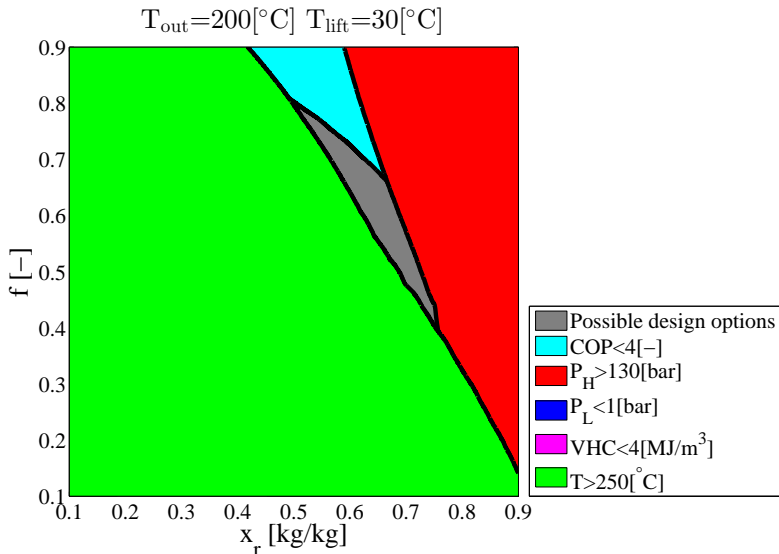


Working domain hybrid heat pumps: $T_{sink,out}$

$$T_{out}=190[^\circ\text{C}] \quad T_{lift}=30[^\circ\text{C}]$$

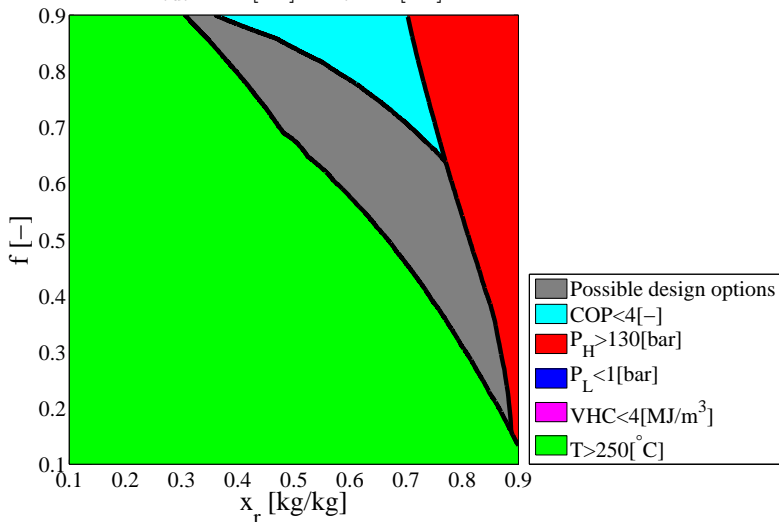


Working domain hybrid heat pumps: $T_{sink,out}$



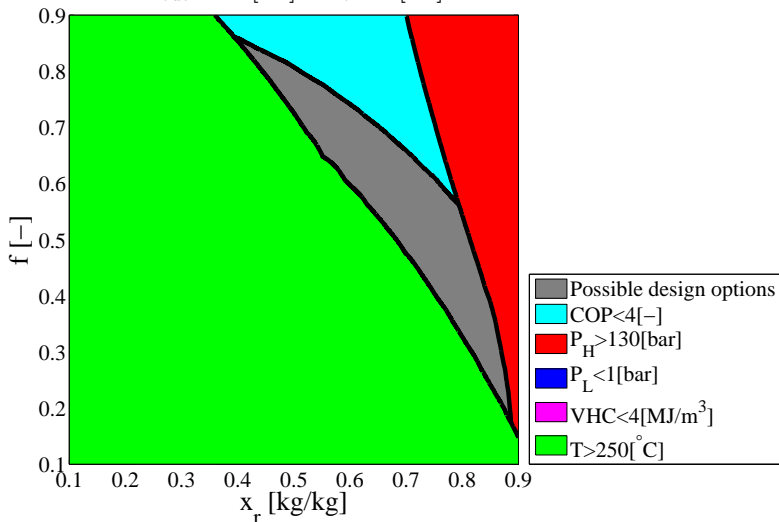
Working domain hybrid heat pumps: ΔT_{lift}

$$T_{out}=180[^\circ\text{C}] \quad T_{lift}=30[^\circ\text{C}]$$



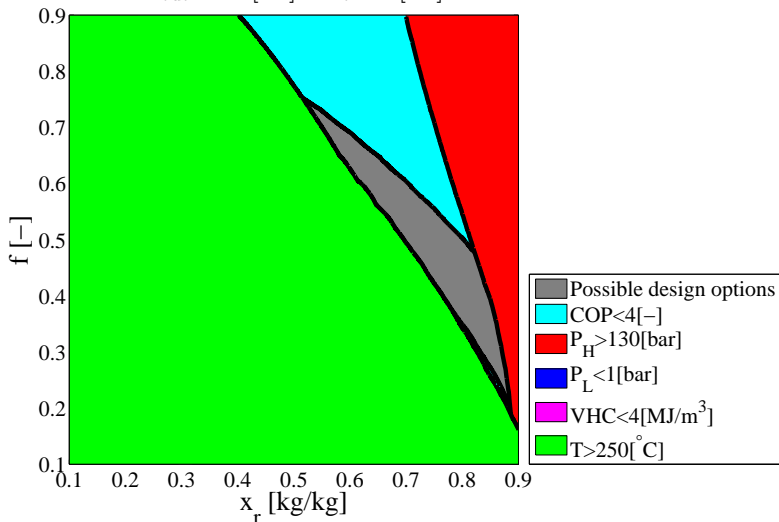
Working domain hybrid heat pumps: ΔT_{lift}

$$T_{out}=180[^\circ\text{C}] \quad T_{lift}=35[^\circ\text{C}]$$



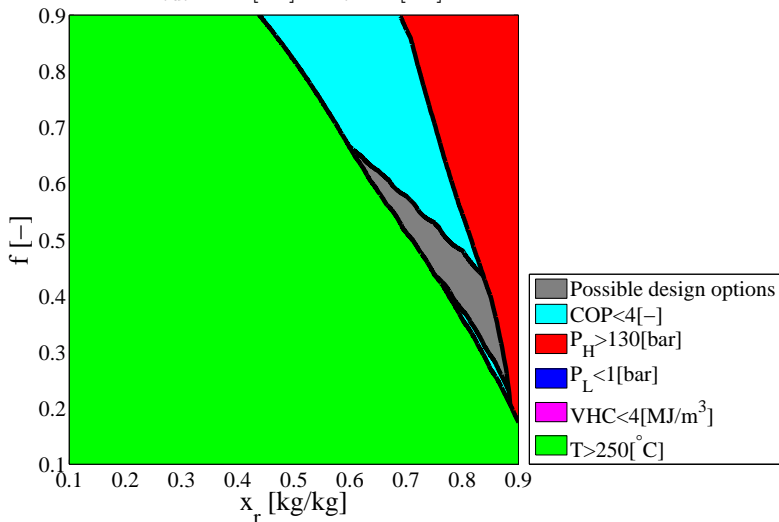
Working domain hybrid heat pumps: ΔT_{lift}

$$T_{out}=180[^\circ\text{C}] \quad T_{lift}=40[^\circ\text{C}]$$

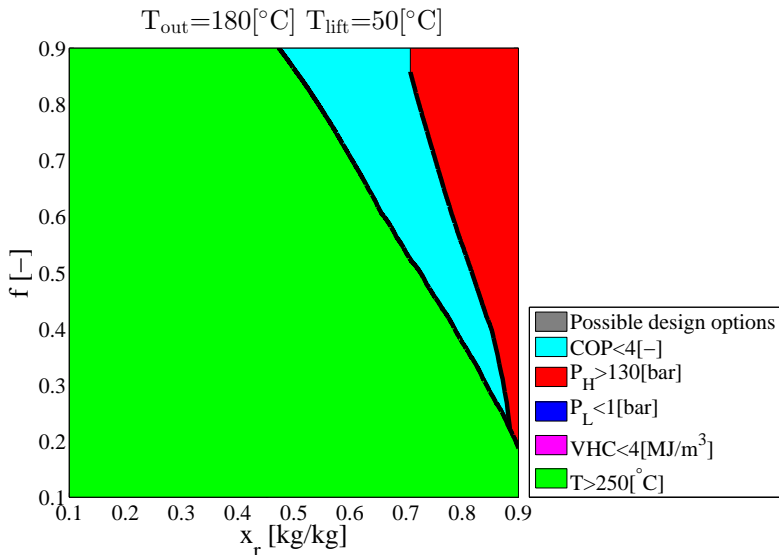


Working domain hybrid heat pumps: ΔT_{lift}

$$T_{out}=180[^\circ\text{C}] \quad T_{lift}=45[^\circ\text{C}]$$

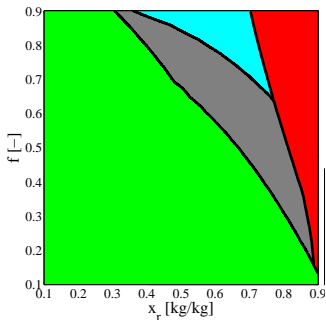


Working domain hybrid heat pumps: ΔT_{lift}



Future work

- Heat transfer characteristics, influence of x_r .
- Identification of suitable oils.
- Material compatibility with $\text{NH}_3/\text{H}_2\text{O}$ should be investigated
- Two-stage concepts should be evaluated, this could reduce compressor discharge temperature and increase COP.
- Thermoeconomic analysis and optimization should be applied to find cost efficient designs.



- COP and design parameters are highly dependent on x_r and f .
- Standard refrigeration components can be used upto 110[°C].
- Supercritical CO₂ components can be used upto 200[°C].
- ΔT_{lift} upto 45[°C] can be attained.
- Dominating constraint is the compressor discharge temperature.
- Hence thermal stability of oil should be tested.
- Case studies should be performed to show the feasibility of the hybrid heat pump implementation.

**Thank you for your attention.
Questions?**